

REMOTELY OPERATED CLOUD CONDENSATION NUCLEUS SPECTROMETER FOR RPV APPLICATIONS

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LONG TERM GOALS

Our long term goal is to understand the contributions of atmospheric aerosols to radiative forcing of the atmosphere. Remotely piloted vehicles (RPVs) present an opportunity to probe atmospheric perturbations caused by aerosol particles for extended periods of time, provided instrumentation can be developed that are sufficiently robust to make the necessary measurements in unattended operation within the size, weight, and power constraints imposed by the aircraft. This project focuses on one of those measurements, the determination of those particles that can be activated under cloud conditions to form cloud water droplets.

OBJECTIVES

In this research project, we seek to develop a cloud condensation nucleus spectrometer system that is suitable for extended, unattended operation aboard a remotely piloted vehicle. The instrument should allow measurement of the distribution of atmospheric aerosol particles with respect to the supersaturation that is required to activate their growth into cloud droplets. The range of supersaturations probed should be relevant to cloud formation, e.g., $0.02\% < S_c < 1\%$. Its operation must be simple and robust, since the RPV does not allow manual adjustment of the instrument in flight. The power, weight, and volume of the instrument must be minimized to work within the severe constraints imposed by RPV operation.

APPROACH

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An automated Cloud Condensation Nucleus Spectrometer (CCNS) has been developed under this program that incorporates concepts from several previous instruments into a single, integrated package. A novel thermal diffusion CCN spectrometer that has been used extensively for airborne CCN measurements was developed by Hudson et al. (Hudson and Alofs 1981, Hudson 1989). Hudson's design imposes a temperature difference gradient *along* the direction of flow. The temperature difference (and therefore also the supersaturation) between the plates increases monotonically with distance traveled into the flow chamber. Particles with small S_c activate earlier than particles with large S_c and, once activated, grow to larger sizes than those that activate later. The CCN spectrum can then be inferred by making a measurement of the size distribution of the droplets at the outlet of the thermal diffusion channel flow. This system is that it can span the entire range of interesting supersaturations and can do so in near real time. Although the instrument developed by Hudson has been used in numerous flights aboard a variety of aircraft to determine CCN spectra, the instrument is ill-suited for operation aboard small aircraft due to its size, weight, and power requirements, and the need for continuous attention from its operator.

An alternate design for a steady-flow thermal diffusion chamber was introduced by Hoppel et al. (1979, 1980). In this device, the gas is passed through a wet wall cylinder with alternating warm and cool sections. After sufficient length that the flow is well developed, the temperature and water vapor concentrations along the centerline are the means of the values in the warm and cool sections, leading to the desired supersaturation. The tube-flow geometry of the alternating gradient diffusion cloud chamber lends itself to the construction of a lightweight instrument suitable for use aboard small aircraft. We have coupled this configuration for the diffusion cloud chamber with the streamwise-gradient concept introduced by Hudson to develop a small, lightweight, and low-power CCN spectrometer.

WORK COMPLETED

The CCN Spectrometer that we have developed incorporates an integral optical particle counter that has been optimized to minimize the degradation caused by Mie resonances to the size/optical signal relationship for water droplets in the 1 to 10 μm diameter size range. The resulting instrument weighs less than 35 pounds, consumes about 100 Watts of 28 volt electrical power, and provides CCN spectra over the range from 0.01 to 0.5% in as little as one minute. The instrument is designed for autonomous operation, and has operated successfully in most of the flights of the CIRPAS Pelican in the ACE-2 experiment.

During this project, the construction and preflight testing of the CCN spectrometer has been completed, and the CCN spectrometer has been deployed aboard the CIRPAS Pelican during the ACE-2 experiment that was based on Tenerife, in the Canary Islands during June and July, 1997. During that field deployment, which was supported by the National Science Foundation, the CCN Spectrometer was successfully used a variety of cloudy column, clear column, and Lagrangian experiments to probe the nature of atmospheric cloud condensation nuclei.

RESULTS

The CCN spectrometer consists of diffusion cloud chamber that is interfaced to an optical particle counter that measures the sizes of the grown particles by light scattering. Sizes of the grown particles are typically in the 1 to 10 μm range where Mie resonances can complicate the size determination. Since the grown droplets are dilute water solutions, the optical properties are well known. The detector was designed to minimize the Mie resonances for water. Calibration with water is, however, problematic due to water's volatility. Figure 1 shows the predicted performance of the detector for water and for diethylsebacate, which is much less volatile and, therefore, better suited to calibration experiments. Also shown are experimental observations for the DES. Although the absolute response differs from that predicted due to incompletely known material parameters, the experimental observations recover virtually all of the structure of the predicted performance with this material. Thus, we have confidence that the performance for water, which shows much less pronounced Mie resonances, will be attained with this detector even though direct calibration is not possible.

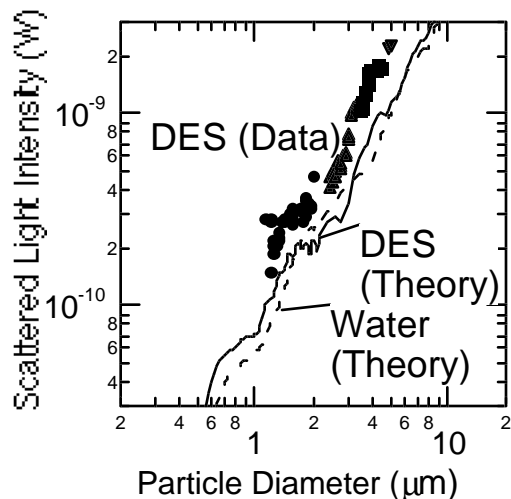


Figure 1. Calibration of the optical particle counter of the CCN spectrometer. The comparison with the diethylsebacate (DES) data is not completely quantitative because some of the property values are not known.

In addition to the calibration of the detector, the response of the streamwise gradient CCN spectrometer must be determined by calibration. Field calibration revealed a smooth, monotonic variation of the peak channel with critical supersaturation. Particles that activate late in the flow down the diffusion cloud chamber tube grow to relatively small sizes and are, therefore, counted into the lower channels. In contrast, those that activate at low S_c grow to much larger sizes and contribute to the higher channels. Noise in the lower channel limited our ability to uniquely identify the particles with very high critical supersaturation. The supersaturation range probed by the instrument is approximately 0.01% to 0.5%, although, due to difficulties encountered in the initial calibration, the absolute response function remains to be determined. Additional instrument characterization studies will, therefore, be needed before the data obtained in the ACE-2 experiment can be fully analyzed. Once that characterization is complete, the instrument will be refined to extend the measurements to higher critical supersaturations.

In spite of this limitation, the present CCN spectrometer provides a unique capability. It is the first streamwise gradient CCN spectrometer that is suitable for unattended airborne operation. It has been successfully deployed in the recent (June/July, 1997) ACE-2 experiment during which it was flown on the CIRPAS Pelican out of Tenerife in the Canary Islands. Figure 2 shows representative data from the July 9, 1997 cloudy column experiment in ACE-2. In these observations, the number of CCN with S_c below 0.2% is measurably lower above cloud than below cloud, and the corresponding critical supersaturations are higher as indicated by the appearance of the peak in the spectrum in a lower channel.

IMPACT

The development of a robust, field deployable cloud condensation nucleus spectrometer is critical to the development of a quantitative understanding of indirect radiative forcing. Previous instruments could only provide data on CCN at a limited number critical supersaturations, or required extensive operator input to maintain quantitative measurements.

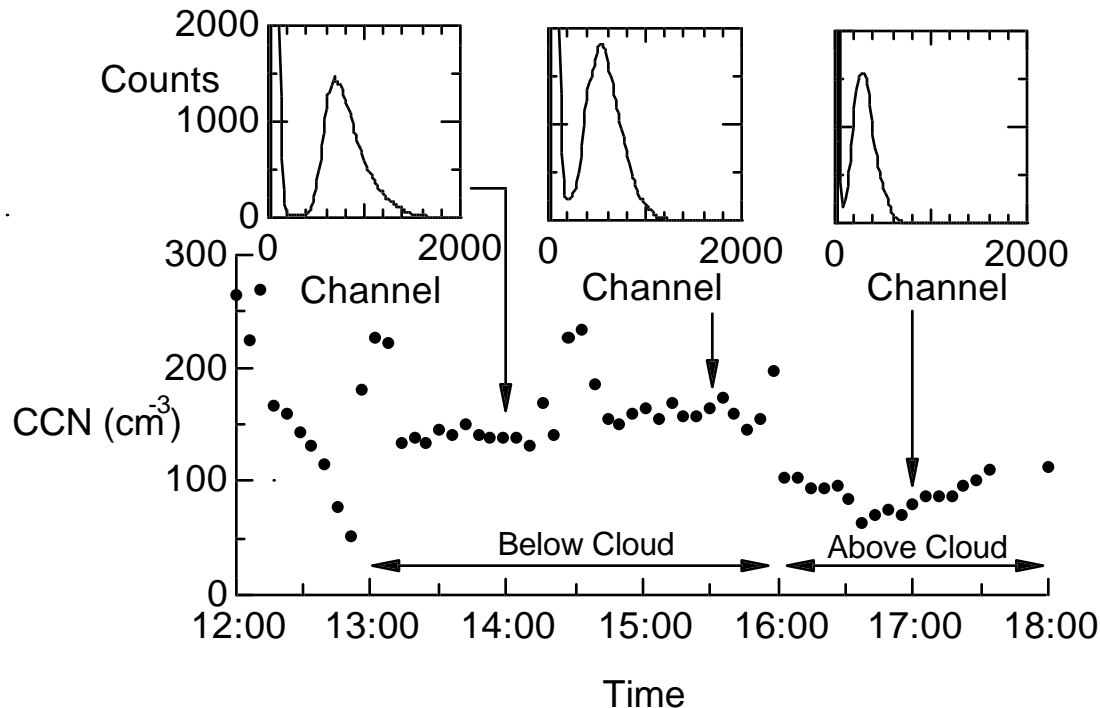


Figure 2. Cloud Condensation Nucleus Spectrometer performance during the July 9, 1997 ACE-2 Cloudy Column Experiment. Total number condensation of CCN corresponding to critical supersaturations below 0.1% are shown.

TRANSITIONS

A patent for the instrument design is been filed to facilitate discussions with instrument companies who might be interested in commercializing the design, thereby making it available to additional research groups around the world.

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